Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Variable-Speed Rotorcraft Drive System Research

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Background

High speed

Variable-speed propulsion (50%)

Applications:

- **Large civil tilt rotor**
- **Joint heavy lift**
- **Unmanned air vehicle**

References:

- Johnson, W., Yamauchi, G.K., and Watts, M.E., "NASA Heavy Lift Rotorcraft Systems Investigation", NASA/TP-2005-213467, Rept-A-0514419, December 2005.
- Acree, C.W., Hyeonsoo, Y., and Sinsay, J. D., “Performance Optimization of the NASA Large Civil Tiltrotor” International Powered Lift Conference, London, UK, July 22-24, 2008.

Objective

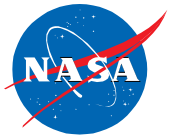
Develop variable-speed drive system technologies for rotorcraft applications to allow 50% speed change of rotors with minimal impact on weight.

State-of-the-Art

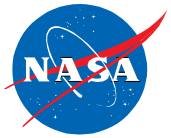
- Most current rotorcraft operate at fixed speed.
- V22: 15% speed change, slowing down engine.
- A160 Hummingbird: two-speed transmission, relatively heavy.
- Automotive: heavy, not enough power capacity.

- Innovative speed change technology required, continued drive system weight reduction required.

Approach



- **Development of variable-speed transmission test facility (in-house).**
- **Development of variable-speed transmission concepts (in-house, industry).**
- **Dynamic modeling of variable-speed drive systems (NASA NRA, Penn St, Univ. of Tennessee).**



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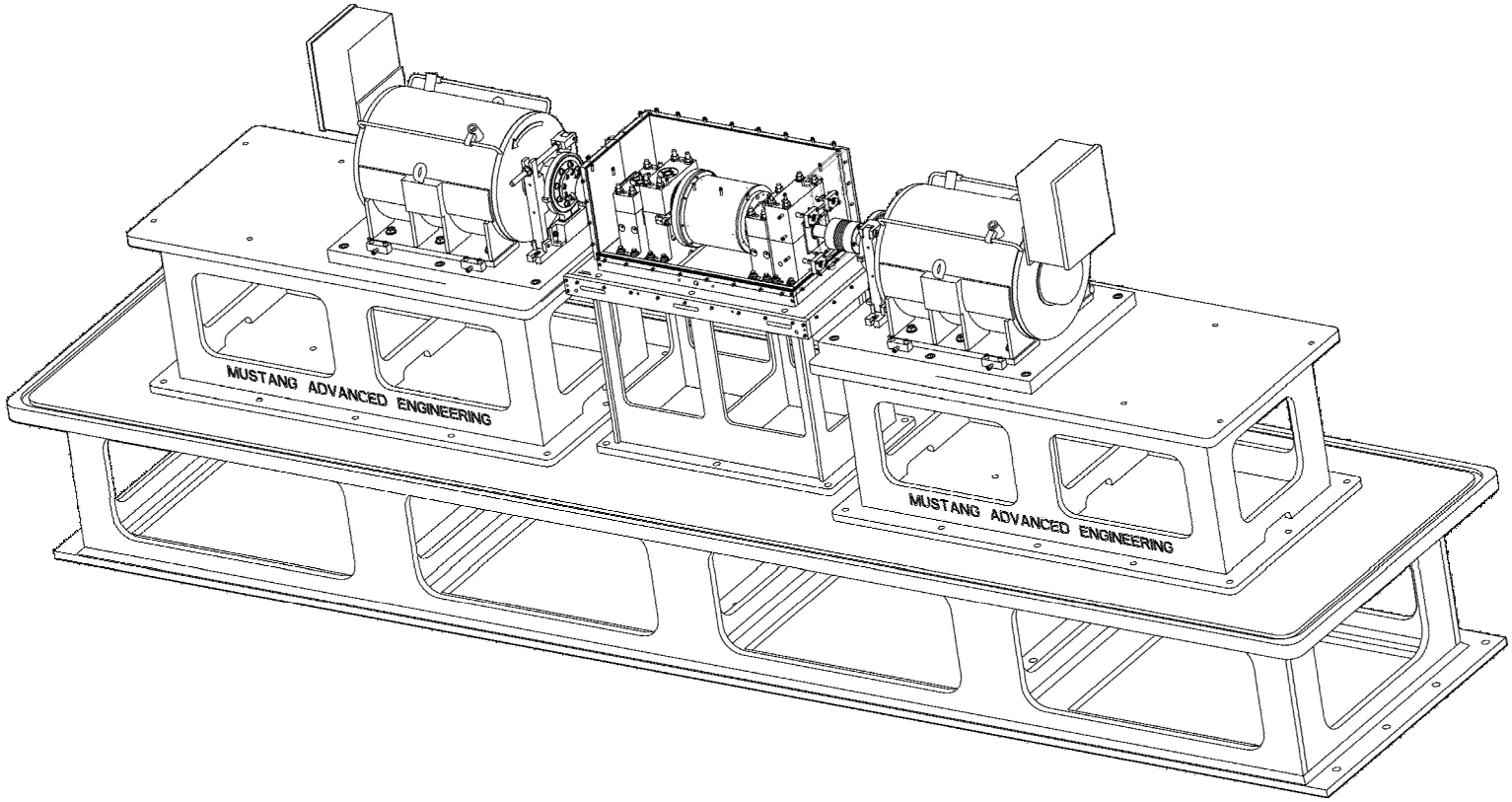
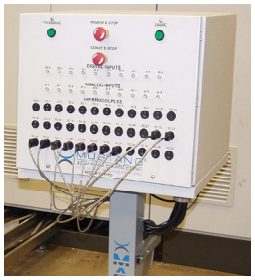
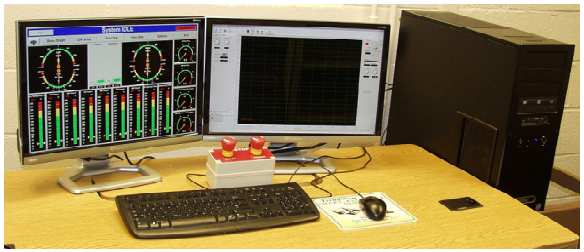
GRC Variable-Speed Transmission Test Facility

- Dual-motor (driver & loader) facility configuration: allows versatility in allowable designs available to test.
- 15000 rpm input speed, 7500-15000 rpm output speed (0-50% reduction ratio).
- Motor power: 140 ft-lb from 0-7500 rpm, 200-hp from 7500-15000 rpm.
- Power regenerative motor configuration.
- State-of-the-art motor controllers & PLC's.
- Allows scripted speed, torque, & clutch loading profiles.



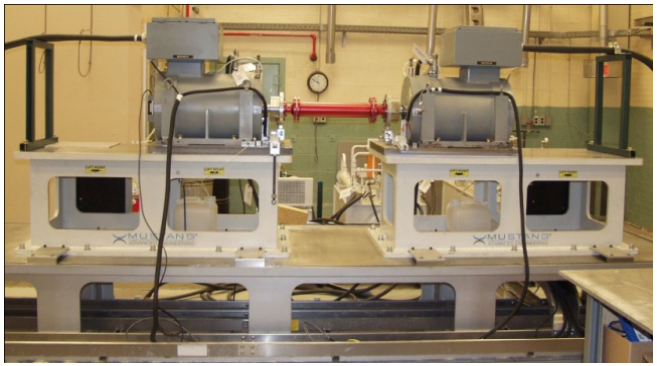
GRC Variable-Speed Transmission Test Facility



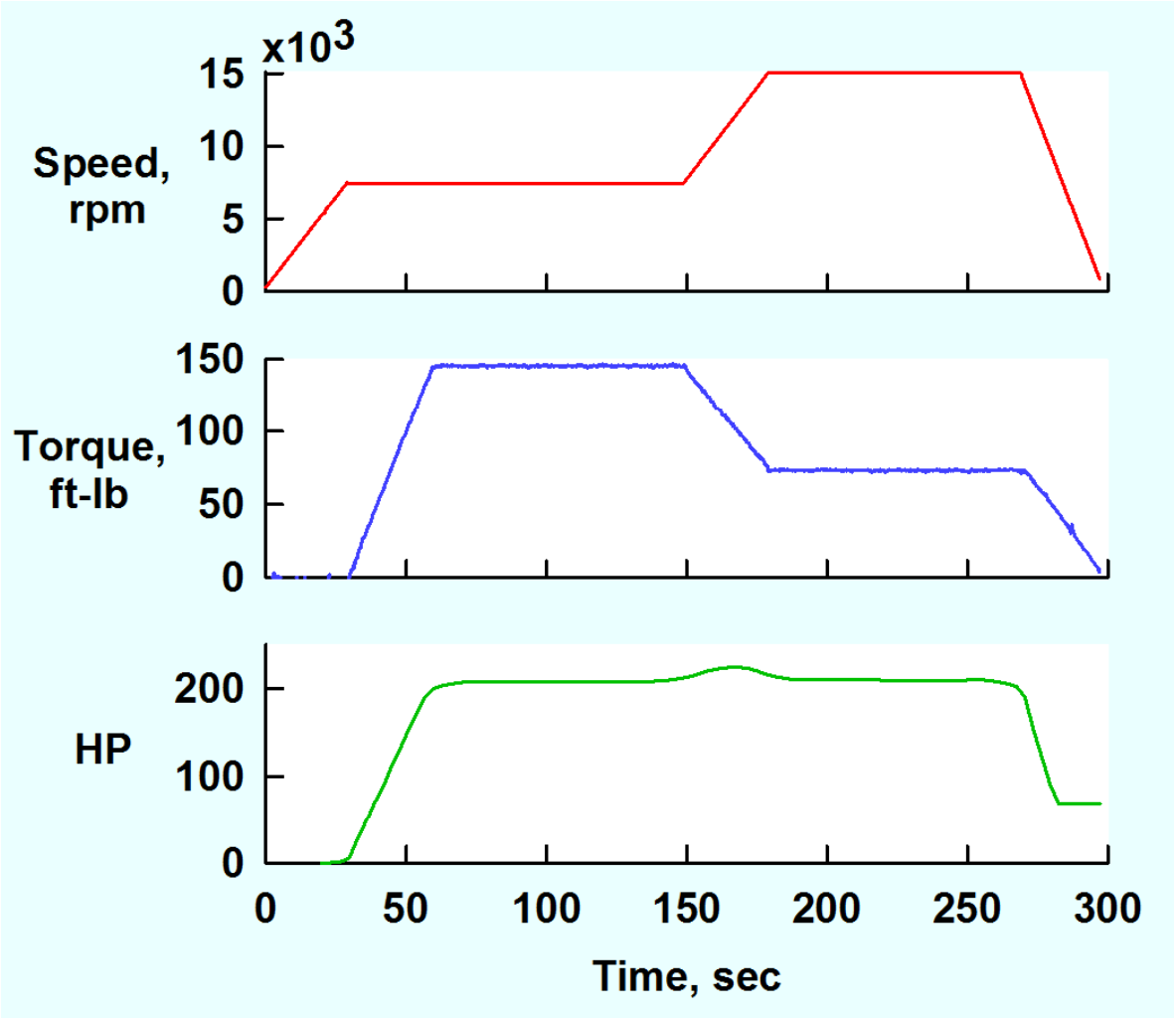


Facility Validation Tests Completed

- **Successfully operated at full speed & torque.**
- **Successfully demonstrated prescribed speed & torque control.**

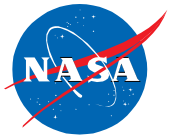


GRC Variable-Speed Transmission Test Facility



Facility Check-Out Test Results

Milestone: (SRW.01.01.108) Complete Fabrication, Assembly, and Check-Out of Variable-Speed Test Facility: 2-23-12



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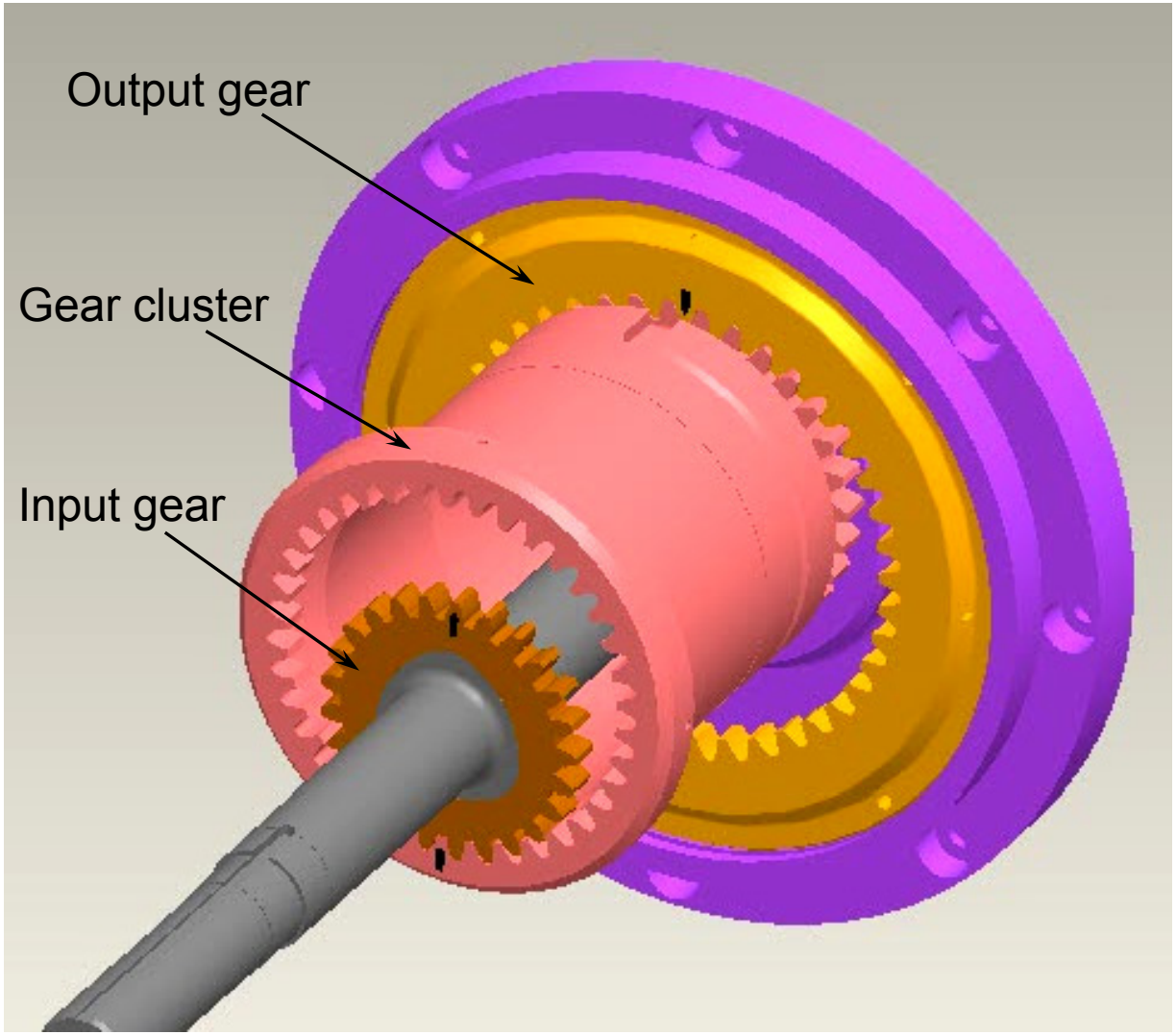
Configurations To Test

1) **Offset Compound Gear Drive w/ Dry Clutch.**
2) **Offset Compound Gear Drive w/ Wet Clutch.**
3) **Double Star Idler Planetary w/ Dry Clutch.**
4) **Double Star Idler Planetary w/ Wet Clutch.**

[1] Stevens, M.A., Handschuh, R.F., and Lewicki, D.G., "Concepts for Variable/Multi-Speed Rotorcraft Drive System", Proceedings of the 64th American Helicopter Society International Forum, Montreal, Canada, April-May 2008 (also NASA TM-2008-215276, Army Research Laboratory Report ARL-TR-4564, AHS Paper No. 080273).

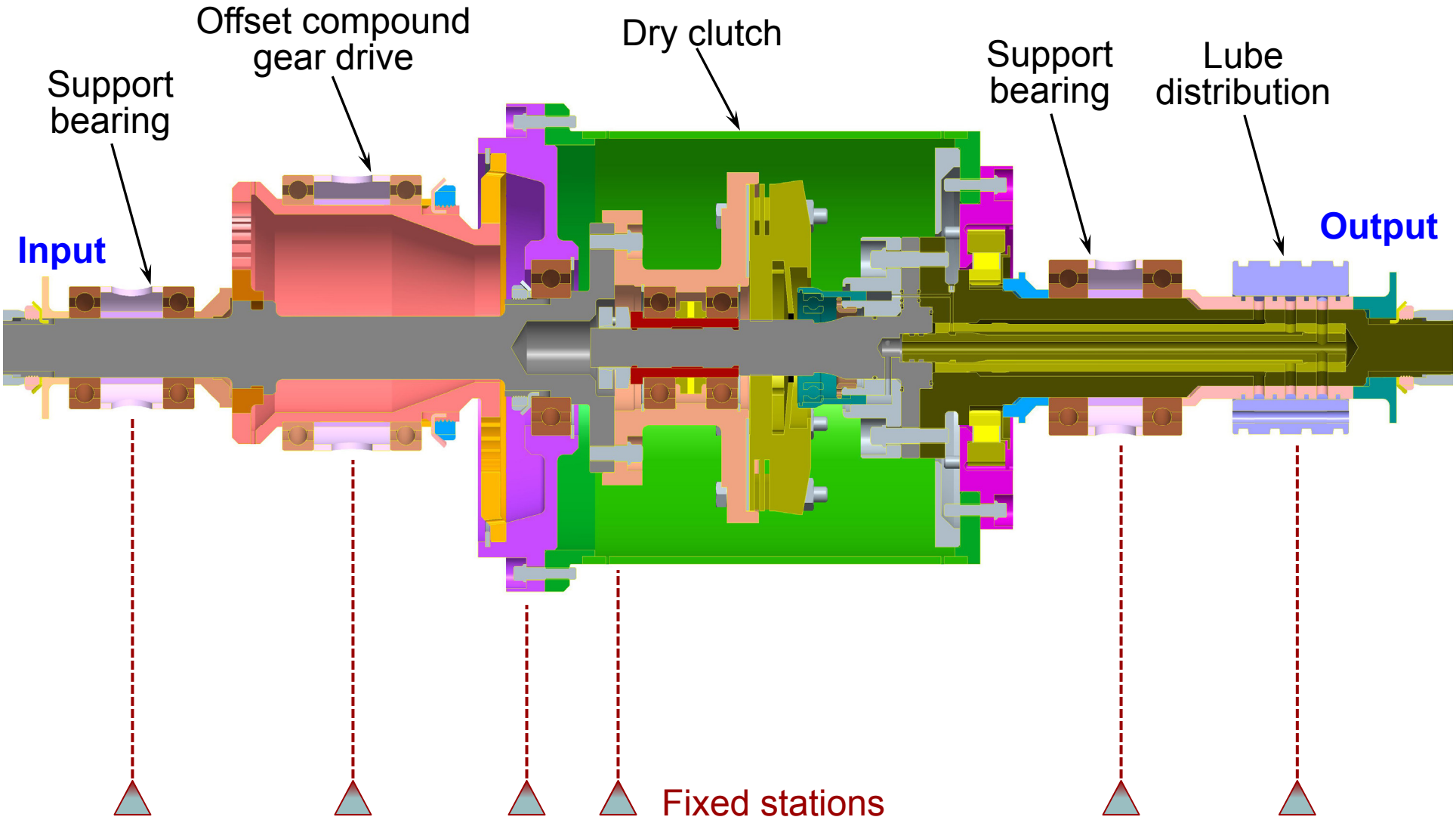
[2] Stevens, M.A., Handschuh, R.F., and Lewicki, D.G., "Variable/Multispeed Rotorcraft Drive System Concepts", NASA TM-2009-215456, Army Research Laboratory Report ARL-TR-4758, March 2009.

Offset Compound Gear Drive

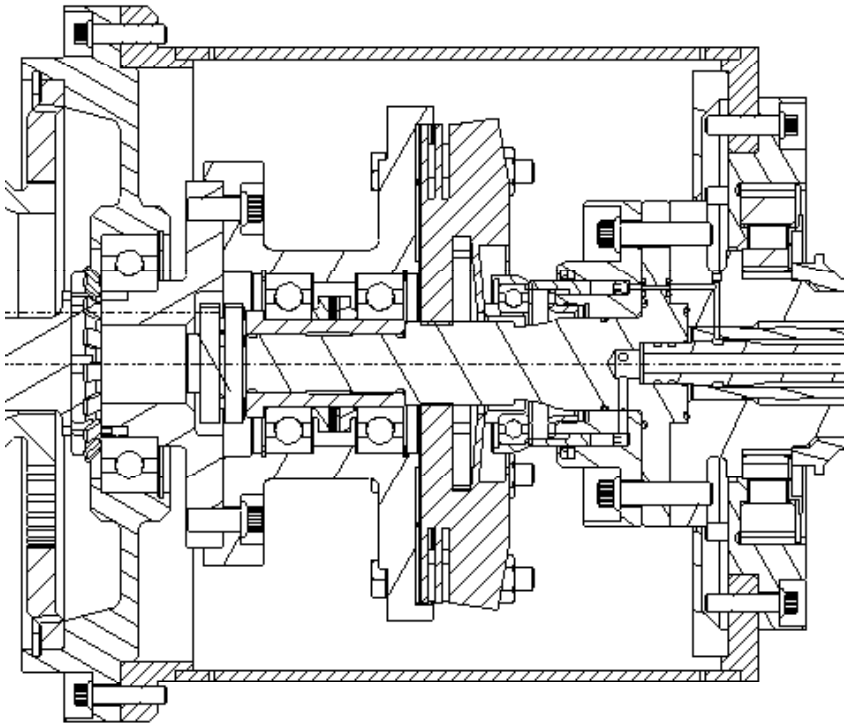


"Offset Compound Gear Inline Two-Speed Drive",
U.S. Patent No. US 8,091,445 B1, Jan 10, 2012.

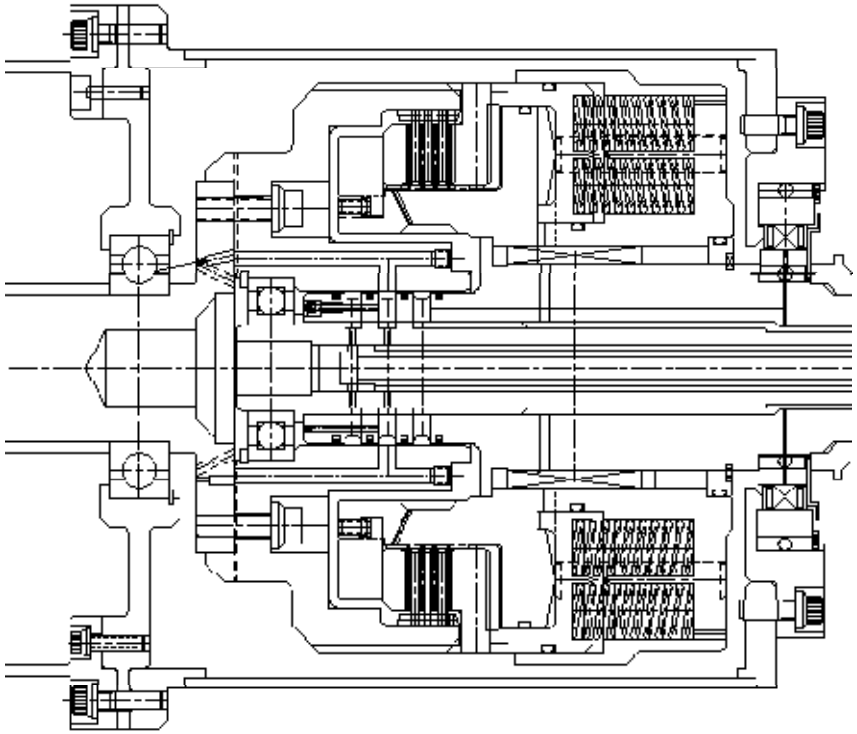
Offset Compound Gear Drive w/ Dry Clutch



Clutches

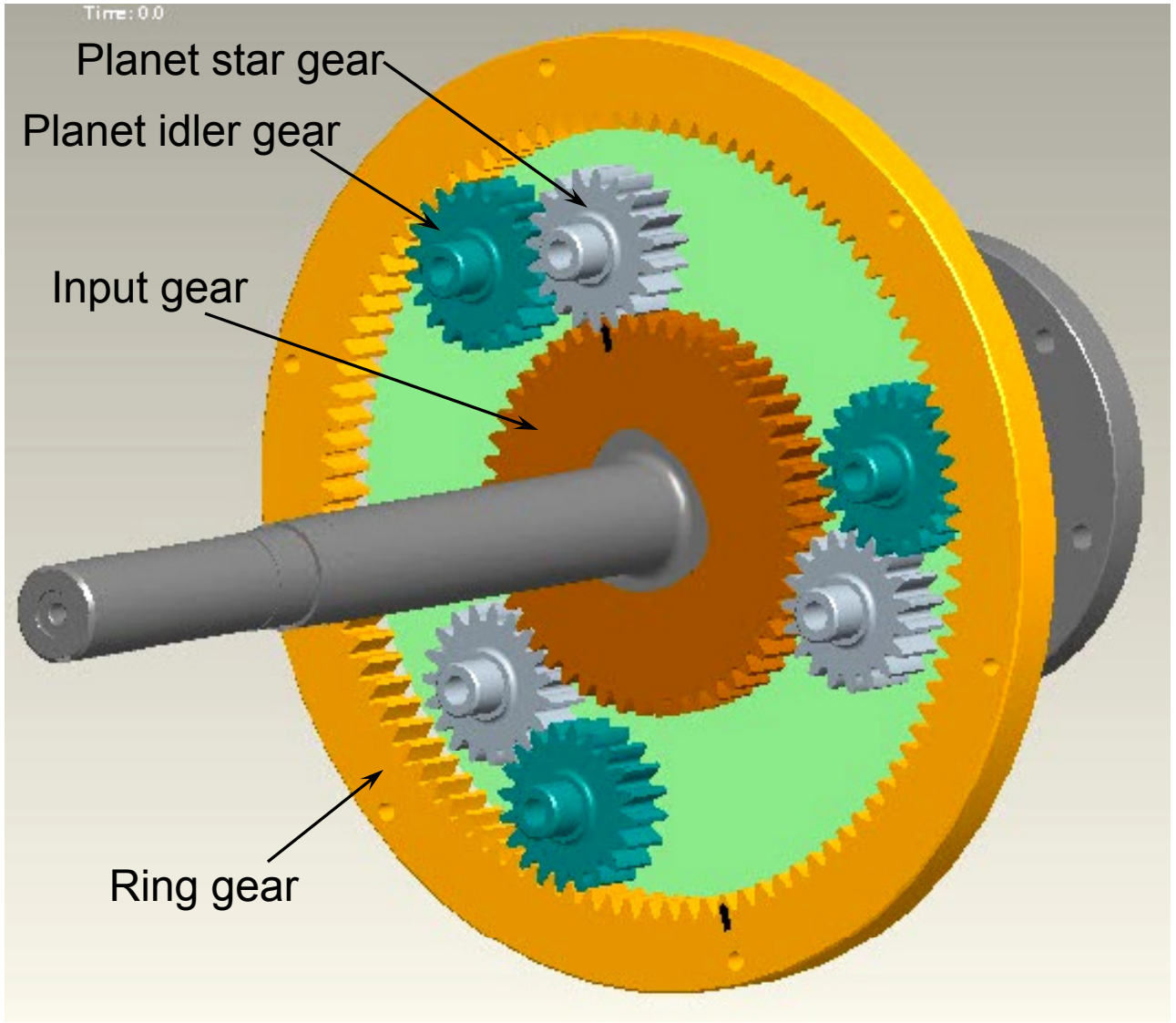


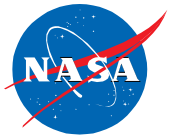
Dry Clutch



Wet Clutch

Double Star Idler Planetary





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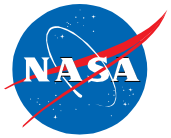
Drive System Dynamic Modeling



NASA/TM—2012-217212 AHS2011–000178

Variable-Speed Simulation of a Dual-Clutch Gearbox Tiltrotor Driveline

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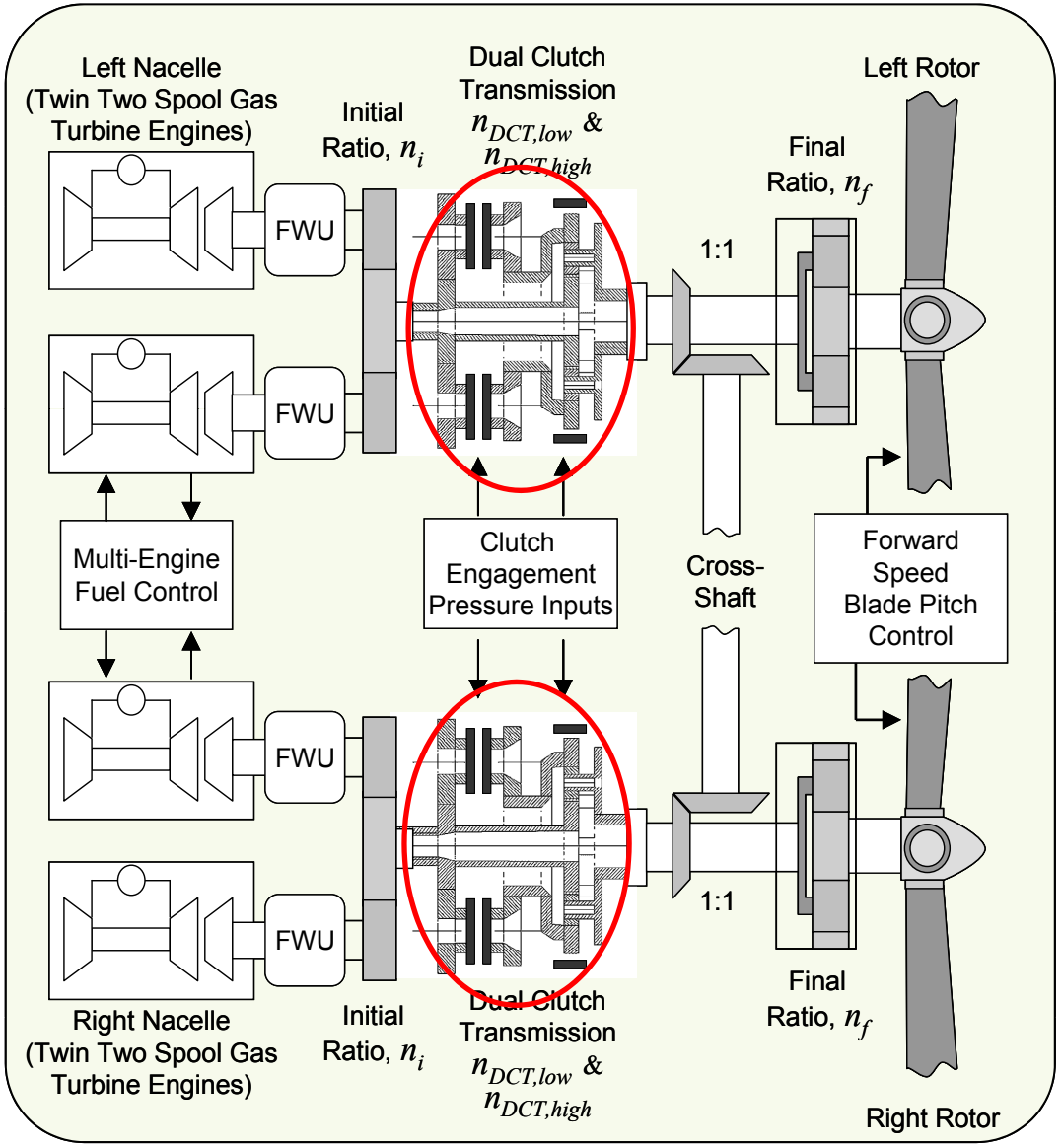
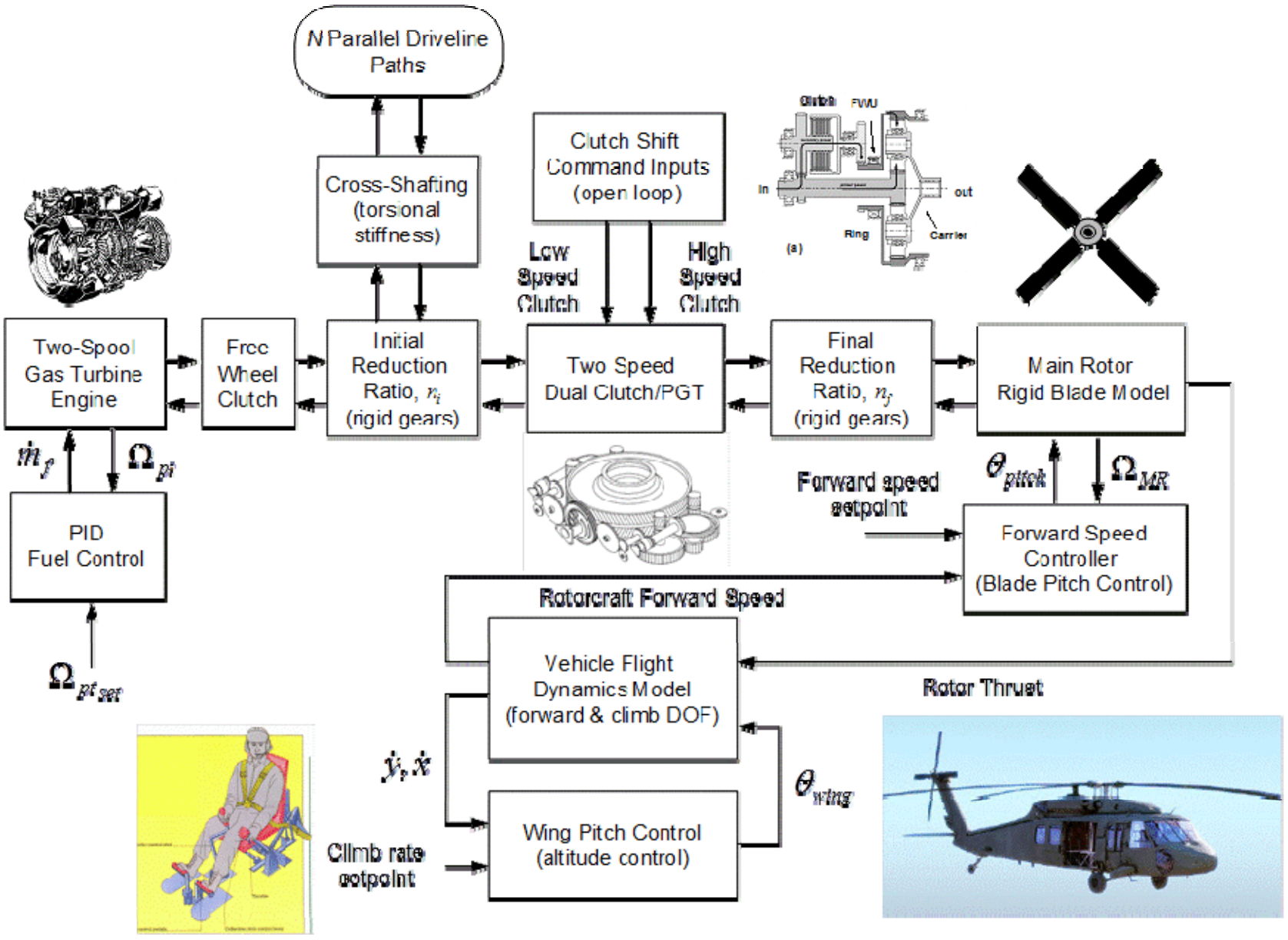
Virginia Beach, Virginia, May 3–5, 2011

Two-Speed Tiltrotor Driveline

- DCTs upstream from cross-shaft
- Maintains rotor indexing phase



Comprehensive Propulsion System Model



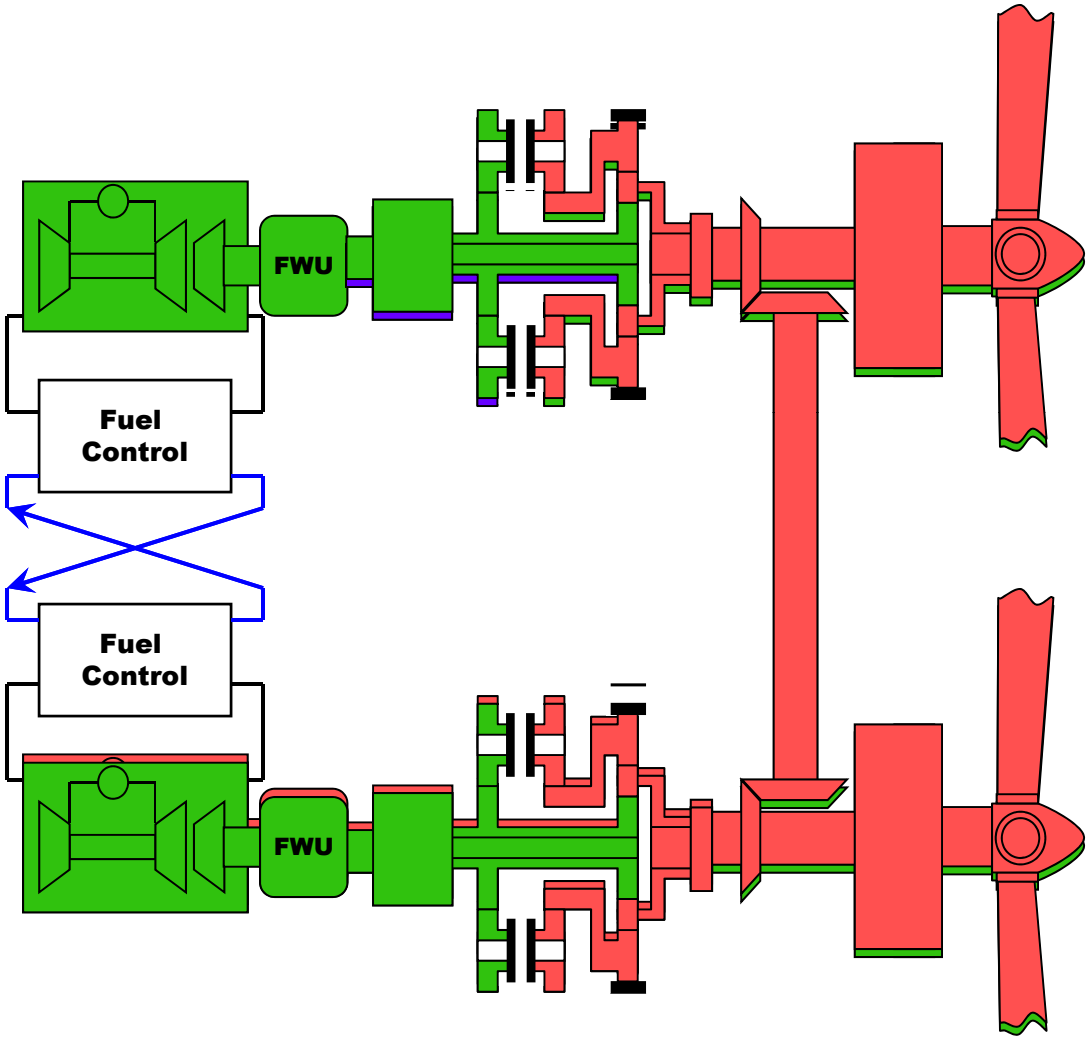
Sequential Shift Control – Downshift

SSC Downshift Sequence:

1. Disable GTE torque sharing control loop
2. Left side DCT downshift
3. Right side GTE ramp-down
4. Right side DCT downshift
5. Right side GTE ramp-up
6. Re-enable GTE torque sharing control loop

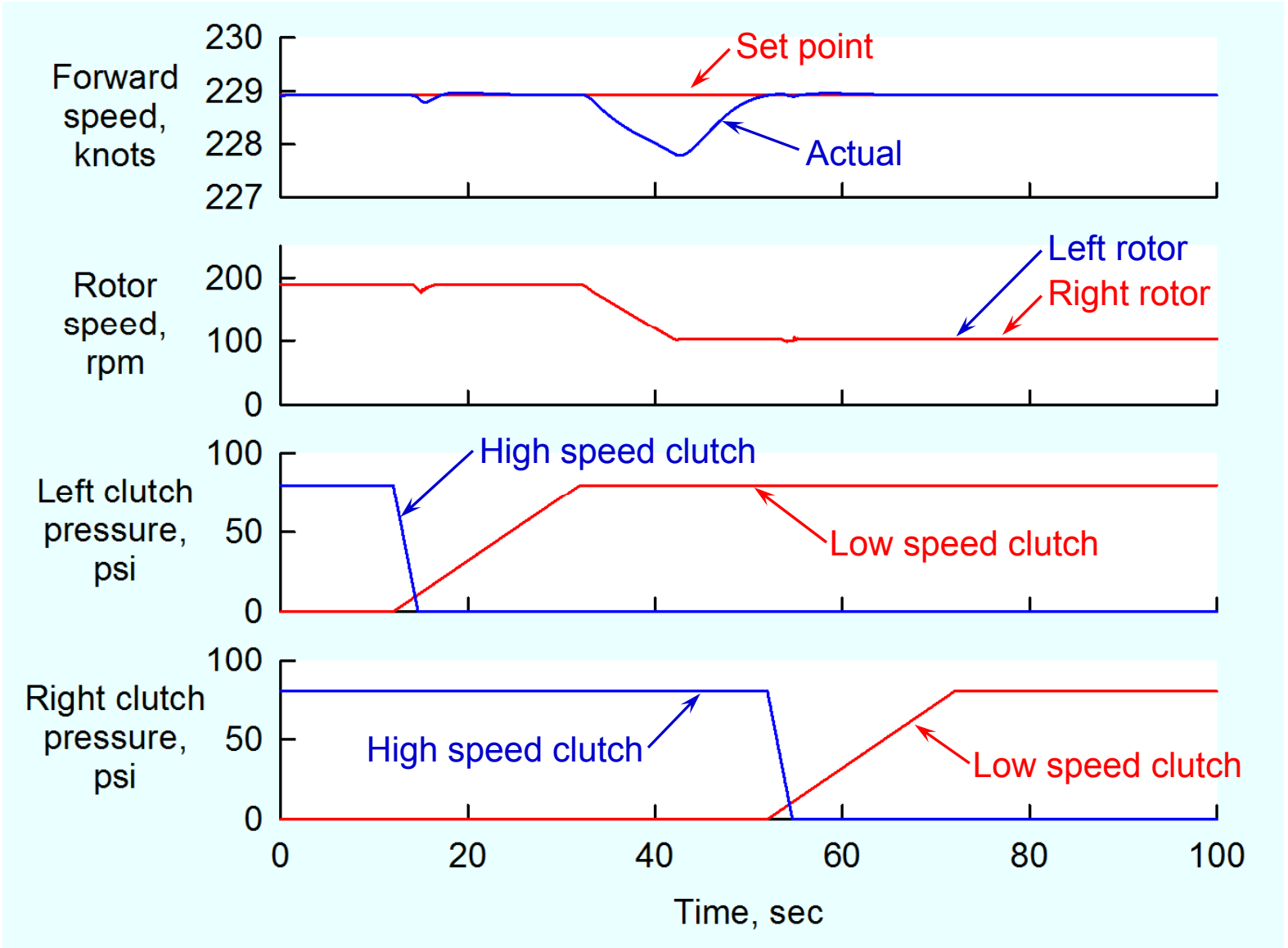
Advantages:

- Always under engine power
- Avoids clutch engagements under full power



Reference: Litt, J.S., Edwards, J.M., and DeCastro, J.A., "A Sequential Shifting Algorithm for Variable Rotor Speed Control," NASA/TM 2007-214842 (2007).

Downshift Example Results



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